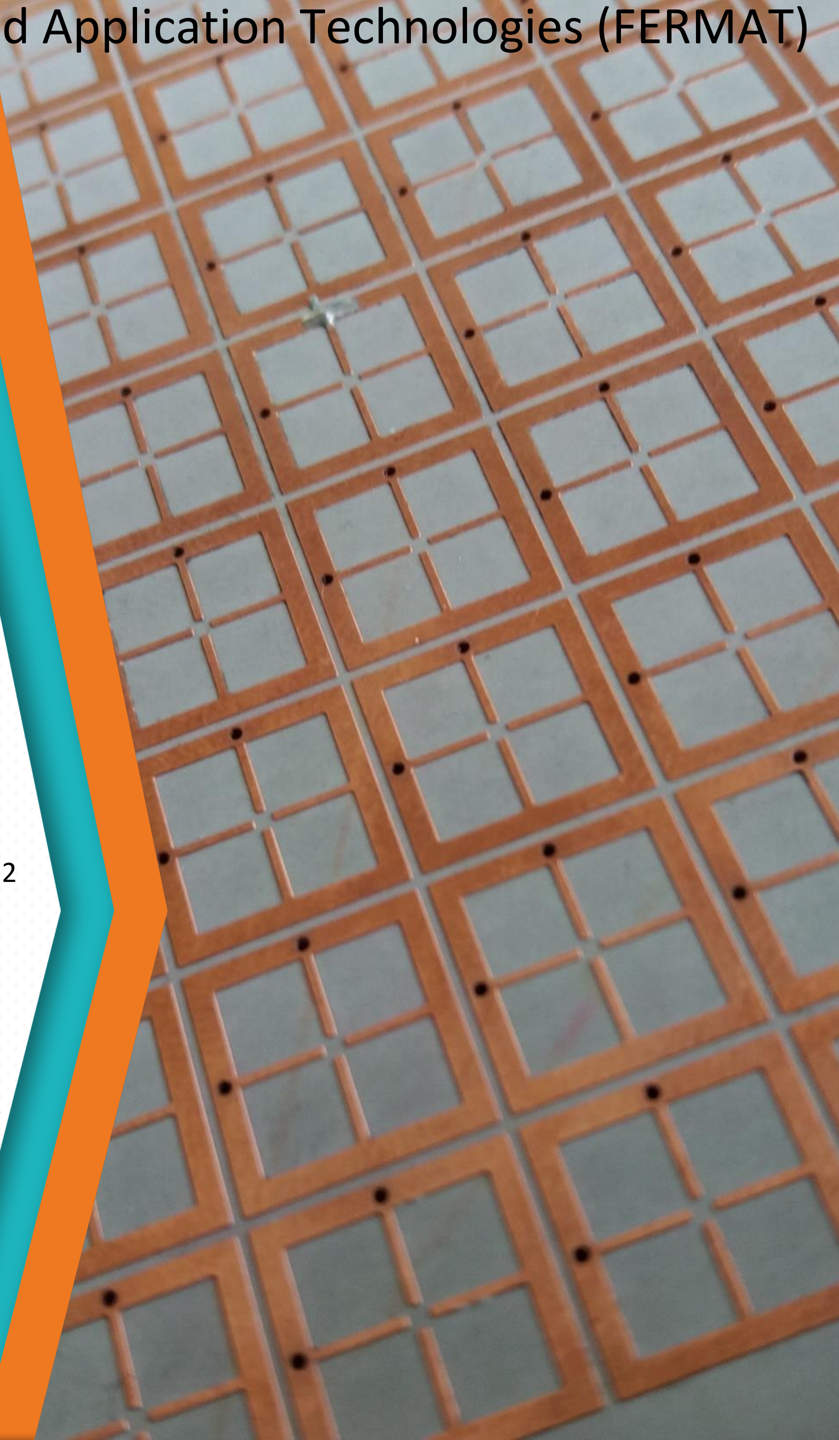
Polarization Independent and Highly Efficient Electromagnetic Energy Harvesting Using Metasurfaces



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Abstract

Recently electromagnetic (EM) energy harvesting using metasurfaces has gained a great attention.

This presentation shows a single band and a double band polarization-independent metasurface harvesters composed of an ensemble of new resonators with a full level of symmetry in a way that their behavior is very insensitive to the polarization of the incident wave.

Loading the resonators with resistors (which model the input impedance of a rectifying circuit in a harvesting system), it is shown that the metasurface perfectly absorbs the incident EM wave (regardless of its polarization) and perfectly delivers the absorbed power to the loads.

Index terms: Metasurface, energy harvesting, pixelization

Biography

Bagher Ghaderi was born in Shahrood, Iran. He received the B.Sc degree from the University of Tabriz, Shahrood, Iran in 2011 and the M.Sc degree from the Iran University of Technology (IUST), Tehran, Iran in 2017 both in electrical engineering. Her research interests include energy harvesting, antennas and radar systems.

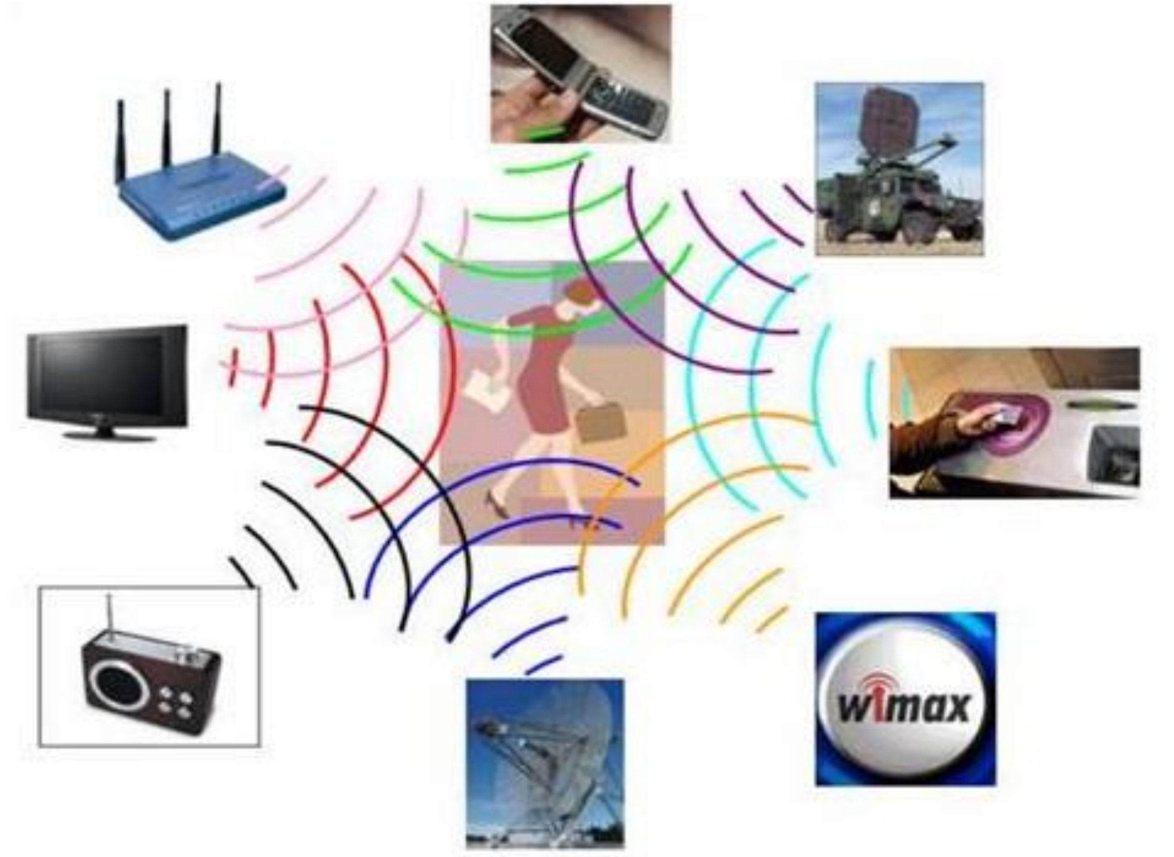
Vahid Nayyeri was born in Tehran, Iran. He received the B.Sc. degree from the Iran University of Science and Technology (IUST), Tehran, Iran, in 2006, the M.Sc. degree from the University of Teheran, Tehran, Iran, in 2008, and the Ph.D. degree from the IUST in 2013, all in electrical engineering.
From 2007 to 2010, he worked as an RF-circuit designer at the IUST satellite research center. He then was the technical manager of three research and industrial projects at the Antenna and Microwave Research Laboratory at IUST. In June 2012 he joined the University of Waterloo, Waterloo, ON, Canada, as a visiting scholar. Presently, he is an assistant professor of the department of satellite engineering, IUST, and also serves as vice-director of Antenna and Microwave Research Laboratory. He has authored and co-authored one book (in Persian) and over 50 journal and conference technical papers. He has been collaborating with Professor Omar M. Ramahi’s group at University of Waterloo, since 2012. His research interests include applied and computational electromagnetics and microwave circuit design.
In 2014, Dr. Nayyeri received the “Best Ph.D. Thesis Award” from the IEEE Iran Section for his research on the modeling of complex media and boundaries in the finite-difference time-domain method. He is a senior member of IEEE and has served as reviewer to several journals and conferences.

Mohammad Soleimani received the B.Sc. degree in electrical engineering from the University of Shiraz, Shiraz, Iran, in 1978 and the M.Sc. and Ph.D. degrees from Pierre and Marie Curio University, Paris, France, in 1981 and 1983, respectively.
He is currently a professor with the school of electrical engineering, Iran University of Sciences and Technology, Tehran, and serves as director of the Antenna and Microwave Research Laboratory. He has also served in many executive and research positions. He has authored and coauthored 19 books (in Persian) and over 200 journal and conference papers. His research interests include electromagnetics, high frequency electronics, antennas.

Omar M. Ramahi was born in Jerusalem, Palestine. He received the BS degree in Mathematics and Electrical and Computer Engineering (Highest Honors) from Oregon State University, Corvallis, OR. In 1990, he was awarded the Ph.D. degree in Electrical and Computer Engineering from the University of Illinois at Urbana- Champaign (UIUC). He then worked at Digital Equipment Corporation (presently, HP), where he was a member of the Alpha Server Product Development Group. In 2000, he joined the faculty of the James Clark School of Engineering at the University of Maryland at College Park as an Assistant Professor and later as a tenured Associate Professor. At Maryland he was also a faculty member of the CALCE Electronic Products and Systems Center. Presently, he is a Professor in the Electrical and Computer Engineering Department, University of Waterloo, Canada. He has authored and co-authored over 400 journal and conference technical papers on topics related to the electromagnetic phenomena and computational techniques to understand the same. He is a co-author of the book EMI/EMC Computational Modeling Handbook, (first edition: Kluwer, 1998, Second Ed: Springer-Verlag, 2001. Japanese edition published in 2005).
Professor Ramahi is the winner of the 2004 University of Maryland Pi Tau Sigma Purple Cam Shaft Award. He won the Excellent Paper Award in the 2004 International Symposium on Electromagnetic Compatibility, Sendai, Japan, and the 2010 University of Waterloo Award for Excellence in Graduate Supervision. In 2012, Professor Ramahi was awarded the IEEE Electromagnetic Compatibility Society Technical Achievement Award.

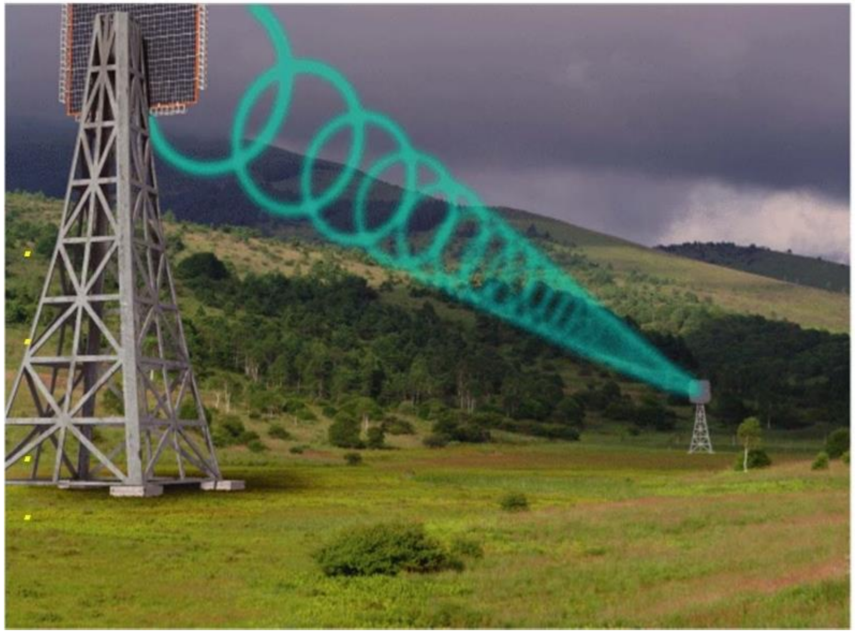
EM Energy Harvesting

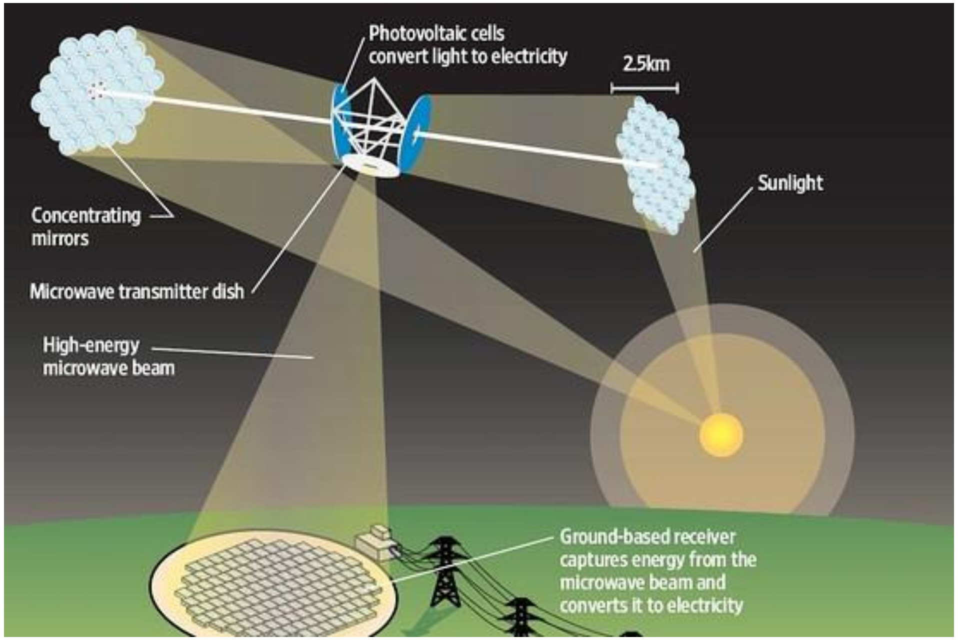
Harvesting from Ambient RF Energy



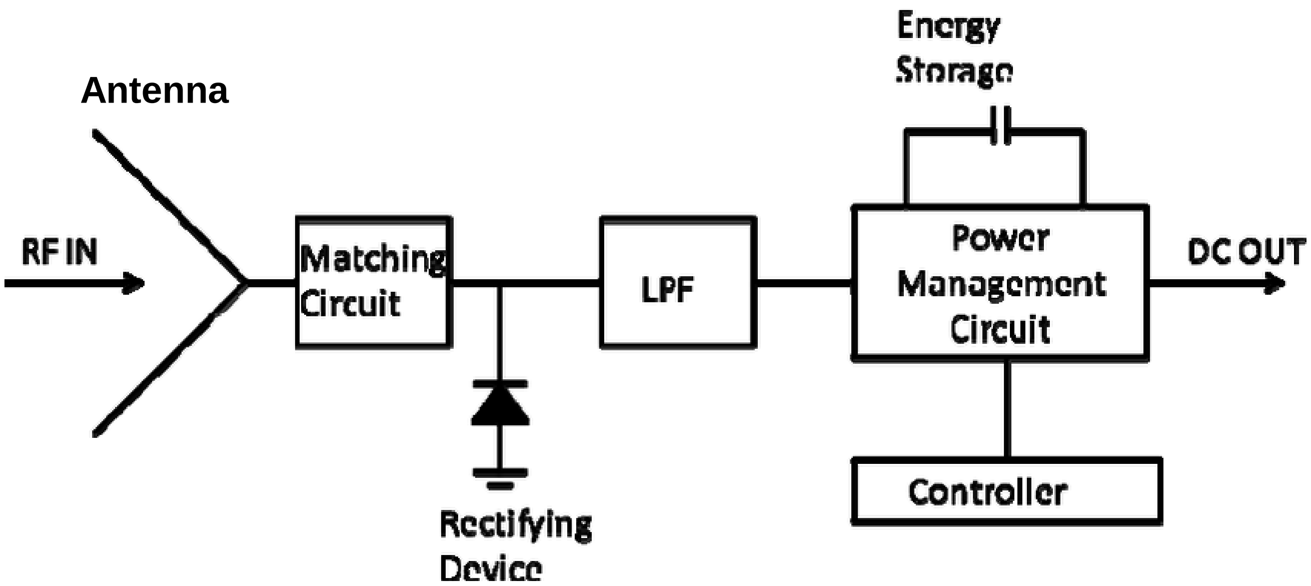
EM Energy Harvesting

Long Range Wireless Power Transfer




Photovoltaic cells convert light to electricity
2.5km
Sunlight
Concentrating mirrors
Microwave transmitter dish
High-energy microwave beam
Ground-based receiver captures energy from the microwave beam and converts it to electricity

Harvesting System

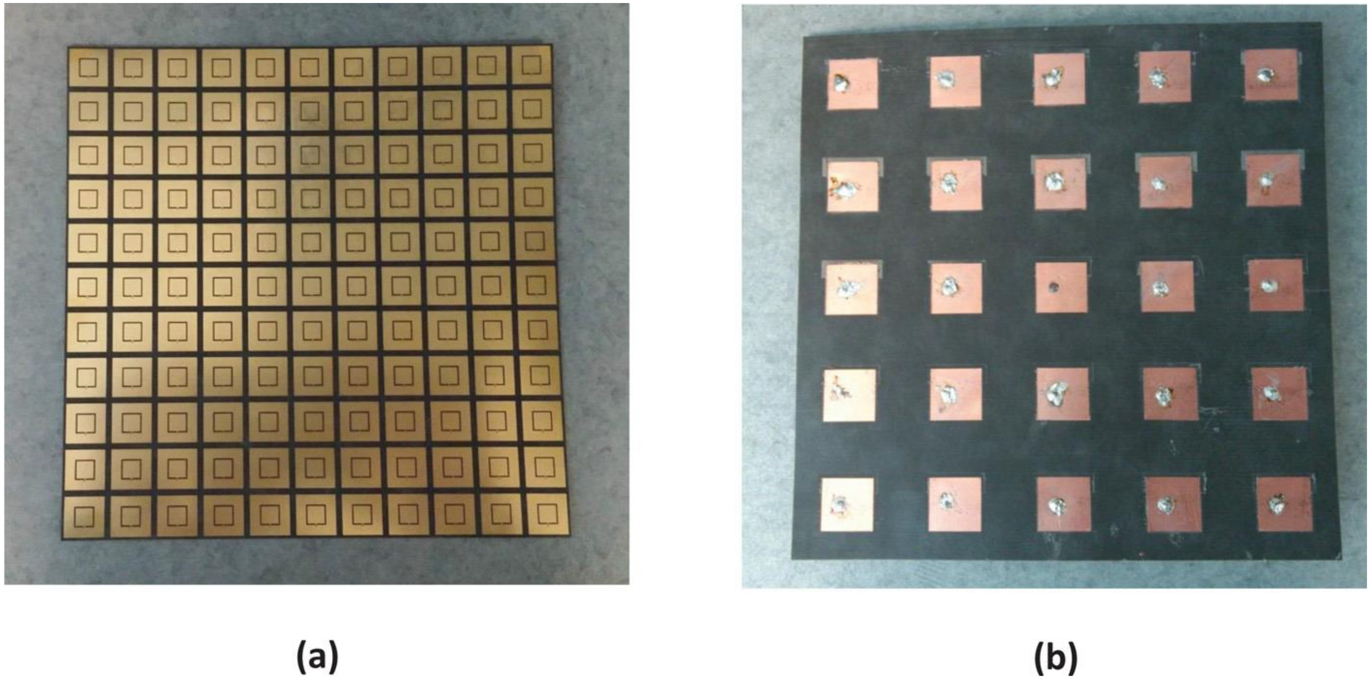

Antenna
RF IN
Matching Circuit
LPF
Energy Storage
Power Management Circuit
DC OUT
Rectifying Device
Controller

Greater amount of energy, larger antenna area:

- Large aperture antennas: heavy and expensive
- Antenna arrays

Metasurface for Energy Harvesting

- Recently, planar array of small resonators (**metasurface**) has been shown to provide a better efficiency than regular antenna arrays like microstrip patch antennas.


(a)

(b)

Alavikia, B., Almoneef, T.S. and Ramahi, O.M., 2015. Complementary split ring resonator arrays for electromagnetic energy harvesting. *Applied Physics Letters*, *107*(3), p.033902.

Metasurface for Energy Harvesting

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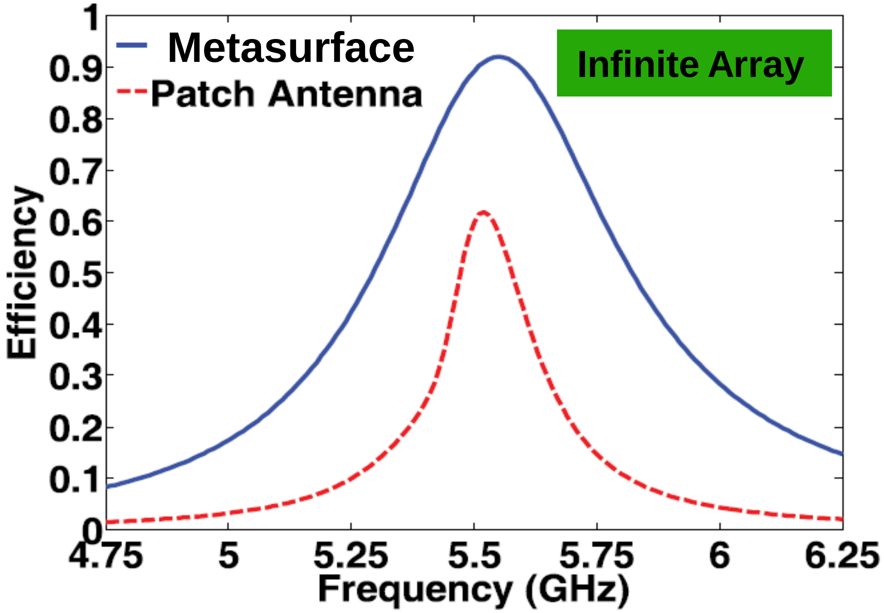
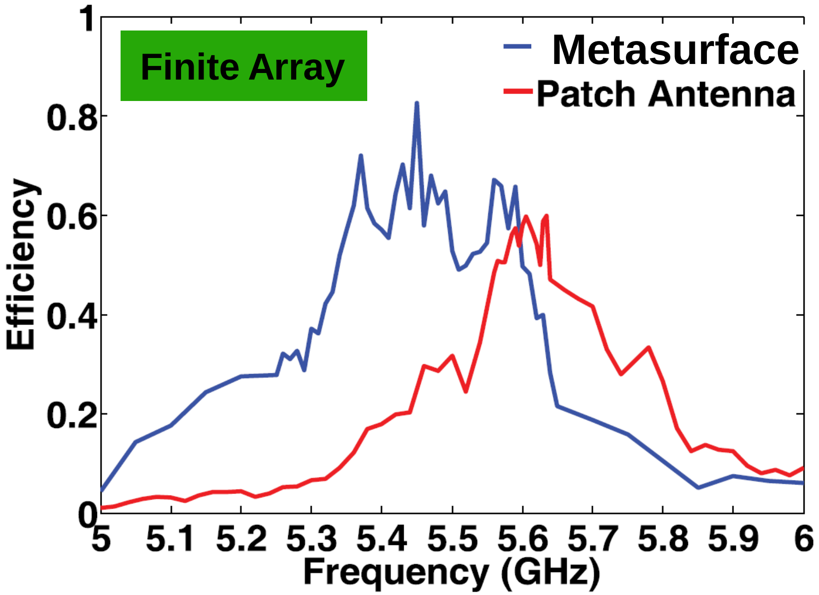
$$\eta = \frac{effective\ area}{physical\ area} = \frac{P_{rec}}{P_{inc}}$$

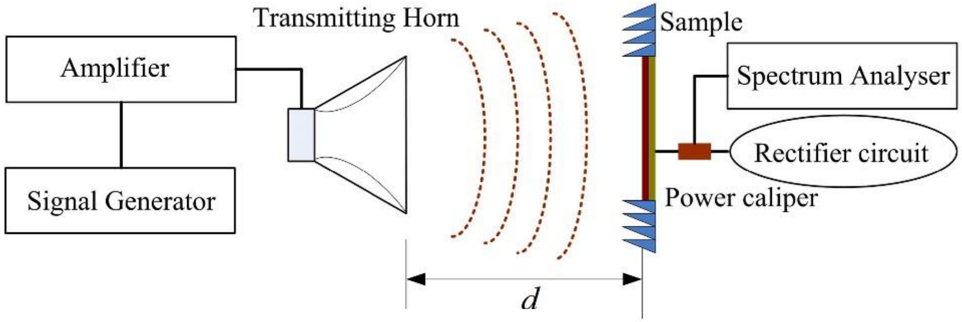


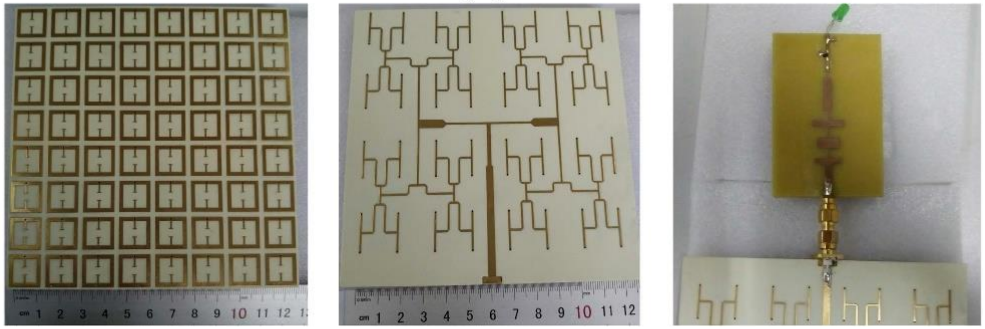


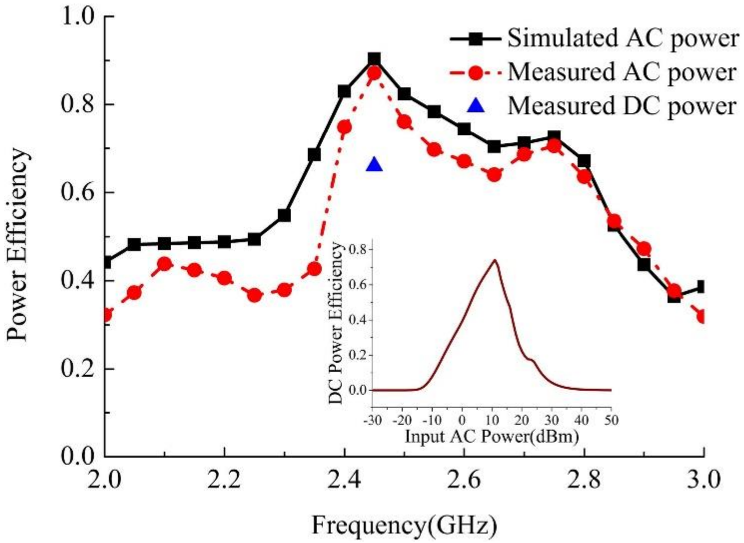
Alavikia, B., Almoneef, T.S. and Ramahi, O.M., 2015. Complementary split ring resonator arrays for electromagnetic energy harvesting. *Applied Physics Letters*, *107*(3), p.033902.

Metasurface for Energy Harvesting

- ➢It has been experimentally shown that it is possible to collect the harvested energy from each cell.


Transmitting Horn
Sample
Amplifier
Spectrum Analyser
Rectifier circuit
Power caliper
Signal Generator
d



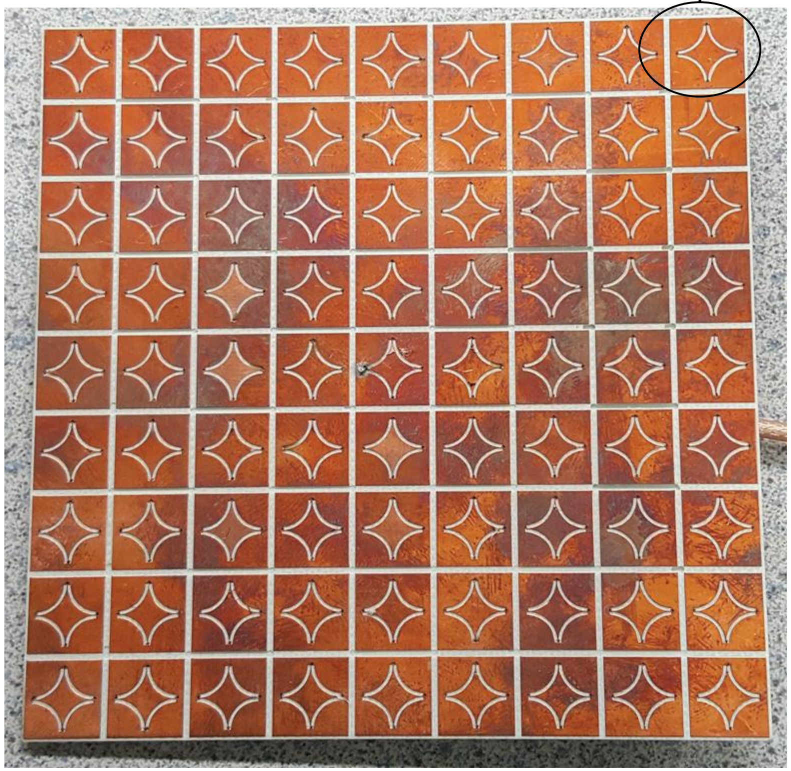


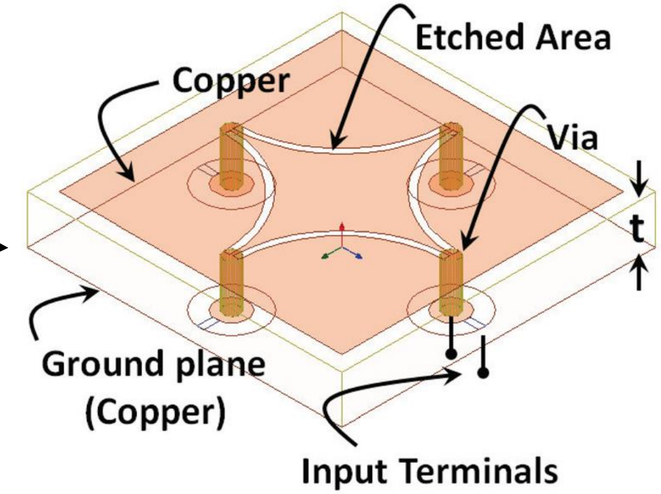
Xu, P., Wang, S.Y. and Geyi, W., 2016. Design of an effective energy receiving adapter for microwave wireless power transmission application. *AIP Advances*, *6*(10), p.105010.

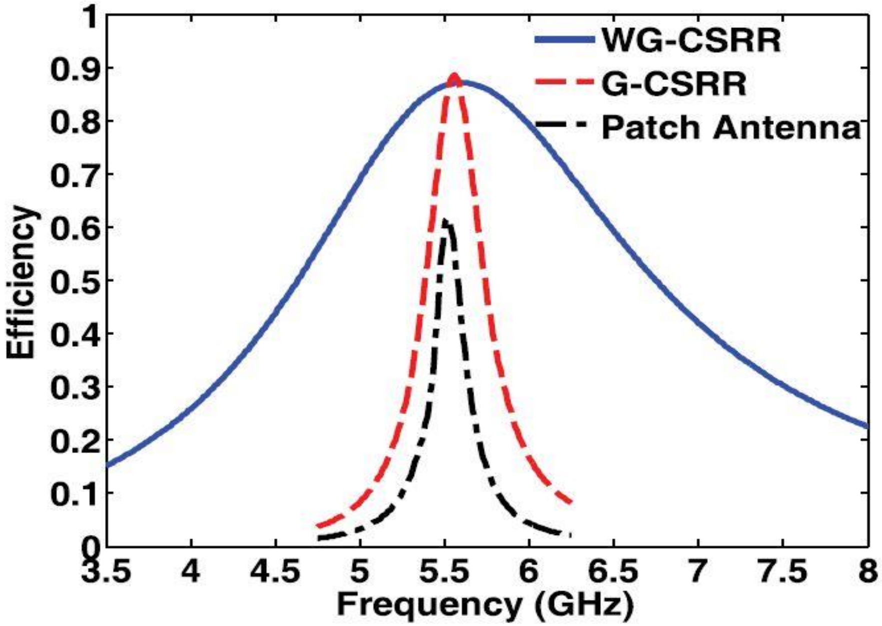
Harvester vs Absorber

- The behavior of a metasurface **harvesters** is similar to that of a metamaterial **absorbers**; however, there is a distinct difference between them:
- In both structures, the resonators efficiently couple to the EM wave in the free space.
- For a **harvesting** application, the captured microwave energy **must be channeled to a resistive load (a grounded resistor)** which models the input impedance of a feed network or rectifying circuit in a complete harvesting system.
- In metamaterial **absorbers**, the absorbed wave **dissipates** either in the structure as dielectric and copper losses or lumped resistors which are placed between two sections of a resonator

In the Literature (Wideband)

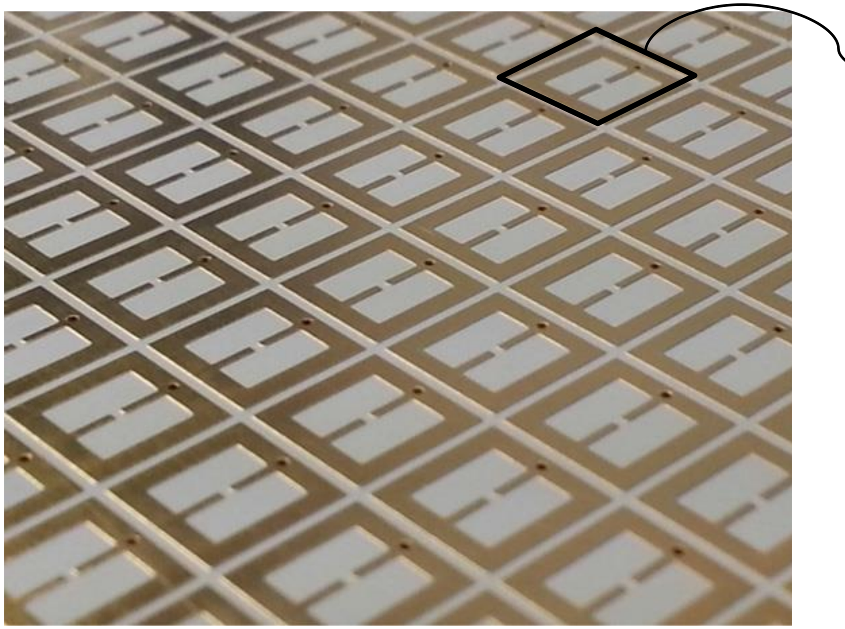


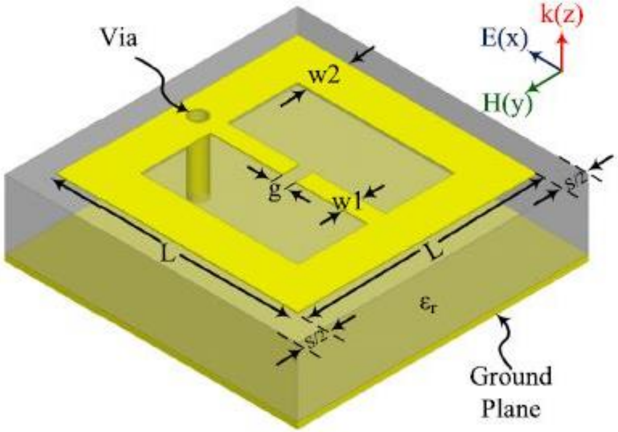

Etched Area
Copper
Via
t
Ground plane
(Copper)
Input Terminals

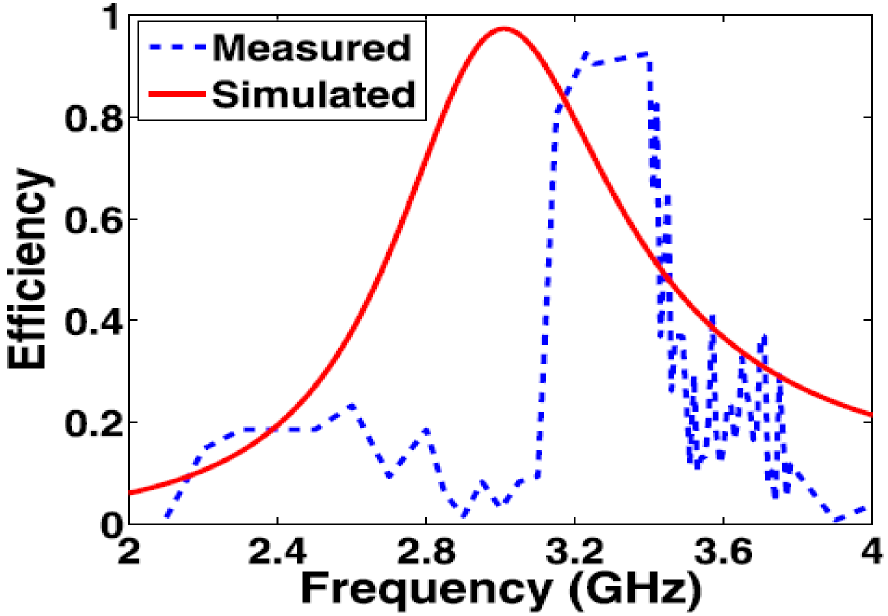


Alavikia, B., Almoneef, T.S. and Ramahi, O.M., 2015. Wideband resonator arrays for electromagnetic energy harvesting and wireless power transfer. *Applied Physics Letters*, *107*(24), p.243902.

In the Literature (near unity efficiency)

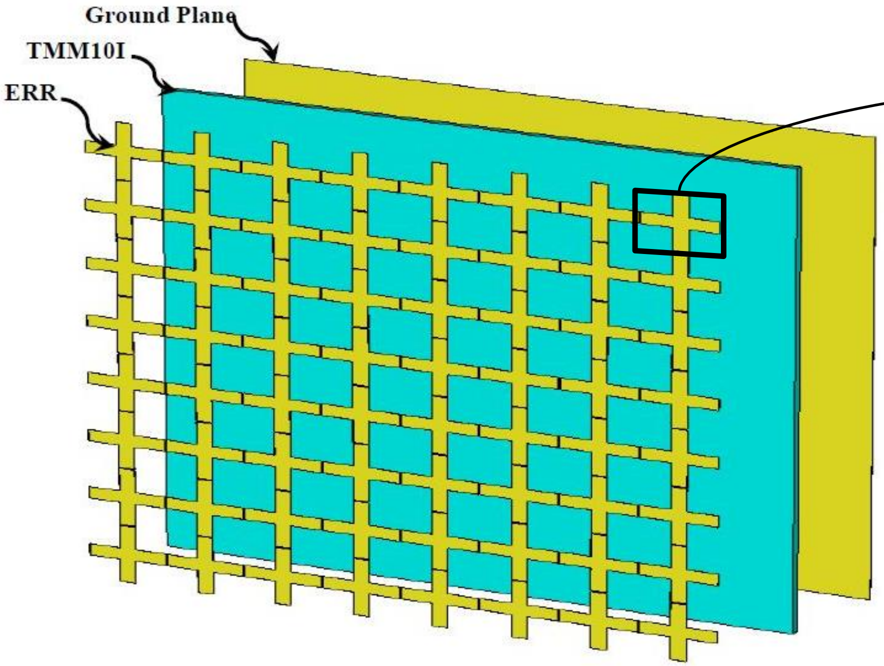


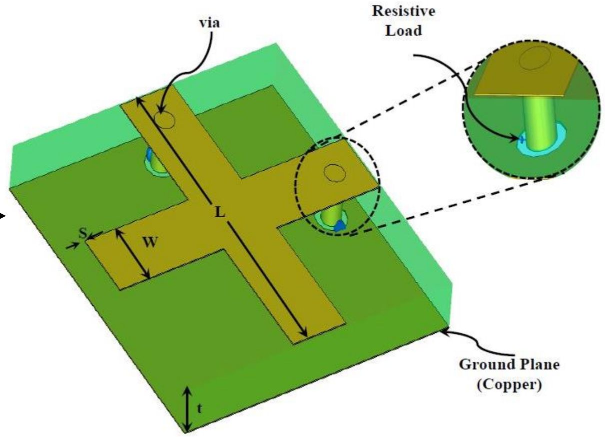

Via
w2
k(z)
E(x)
H(y)
g
w1
L
L
s/2
s/2
εr
Ground
Plane

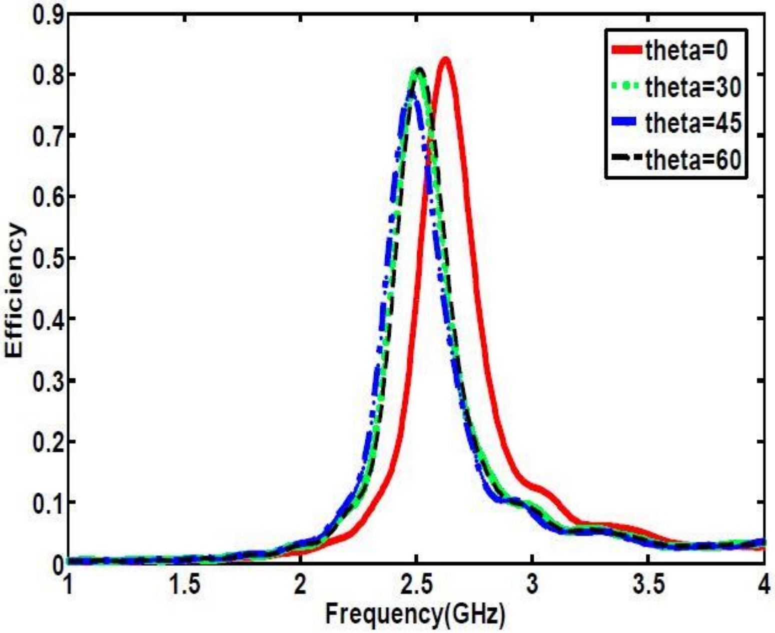


Almoneef, T.S. and Ramahi, O.M., 2015. Metamaterial electromagnetic energy harvester with near unity efficiency. *Applied Physics Letters*, *106*(15), p.153902.

In the Literature (Dual Polarization)

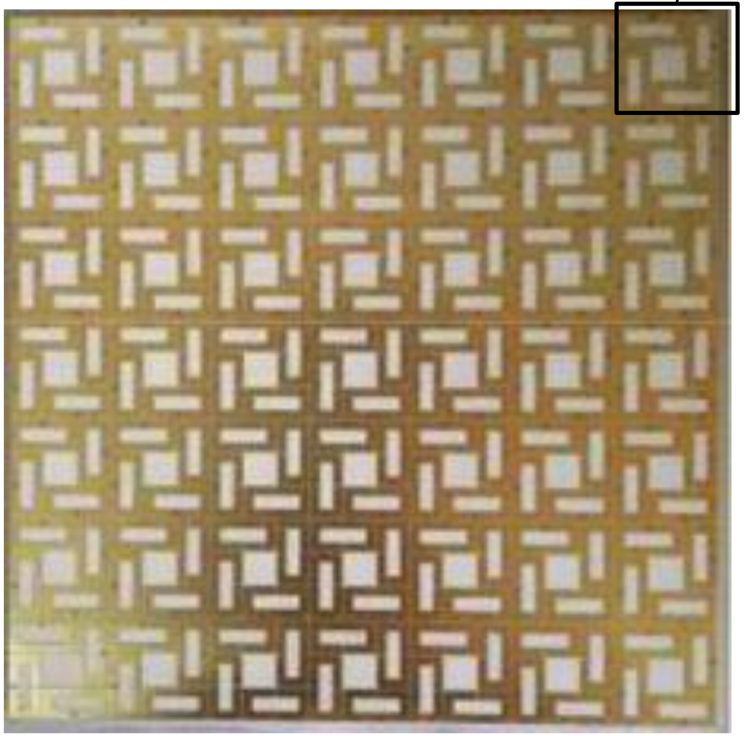

Ground Plane
TMM10I
ERR

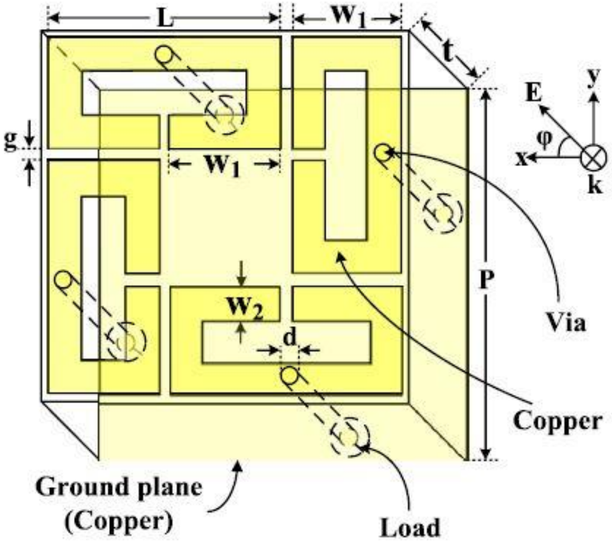

via
Resistive Load
L
S
W
Ground Plane (Copper)
t

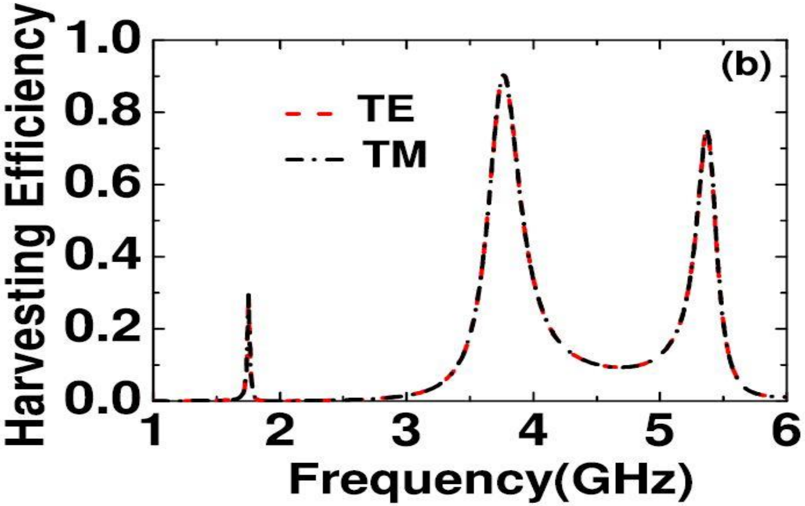


El Badawe, M. and Ramahi, O., 2016, April. Polarization independent metasurface energy harvester. In *Wireless and Microwave Technology Conference (WAMICON), 2016*

In the Literature (Dual Pol. & Dual Band)

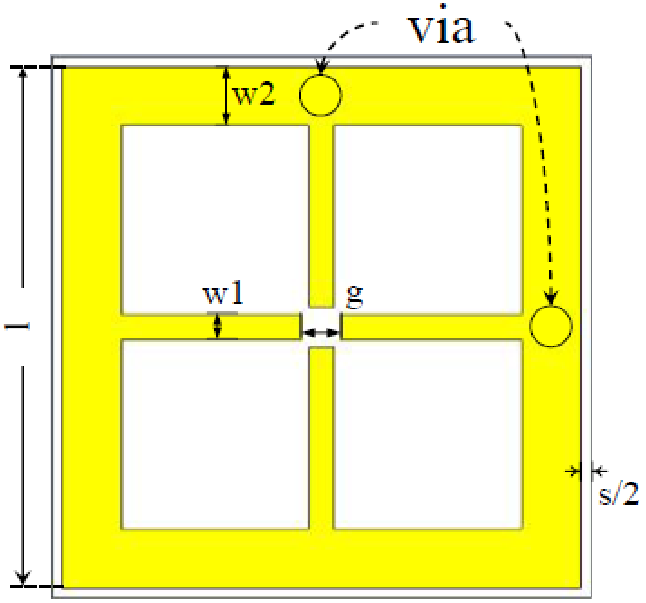



L
W_1
t
g
W_1
E
y
φ
x
k
P
Via
W_2
d
Copper
Ground plane
(Copper)
Load

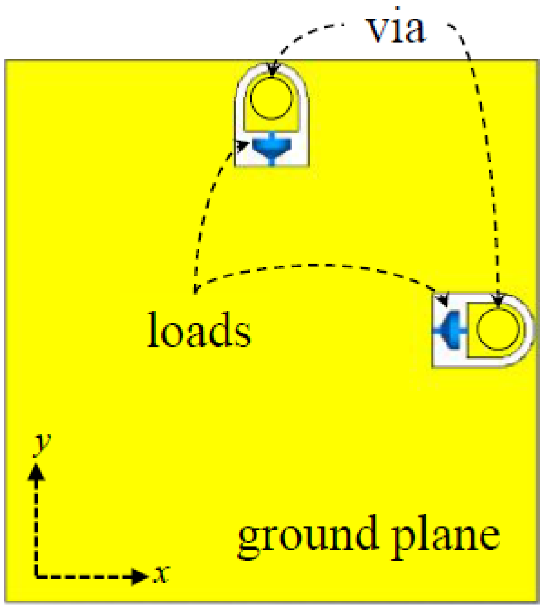


Zhong, H.T., Yang, X.X., Tan, C. and Yu, K., 2016. Triple-band polarization-insensitive and wide-angle metamaterial array for electromagnetic energy harvesting. *Applied Physics Letters*, *109*(25), p.253904.

Proposed Resonator for Dual Pol.


via
w2
w1
g
l
s/2

Top View

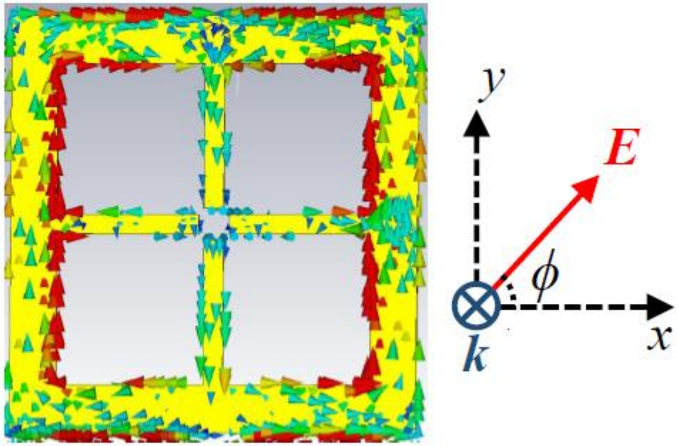

via
loads
y
x
ground plane

Bottom View

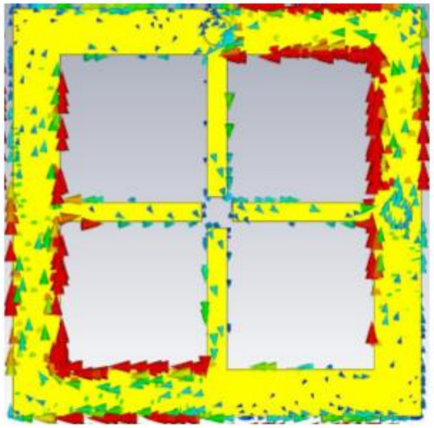
Parameter	l	w1	w2	s	g	via diameter	R
Value	10.5 mm	0.5 mm	1.2 mm	0.4 mm	0.8 mm	0.7 mm	160 ohms

Dielectric substrate: Rogers RT/duroid 6006, thickness 100 mil

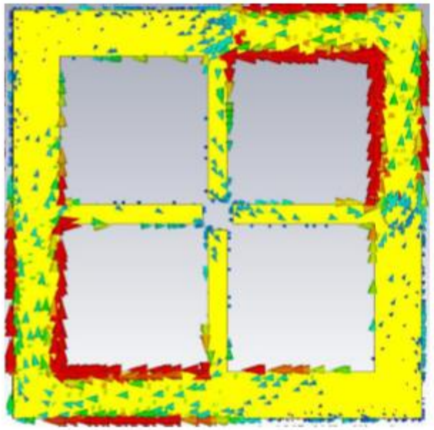
Surface Current Density



ϕ= $90^{\square}$

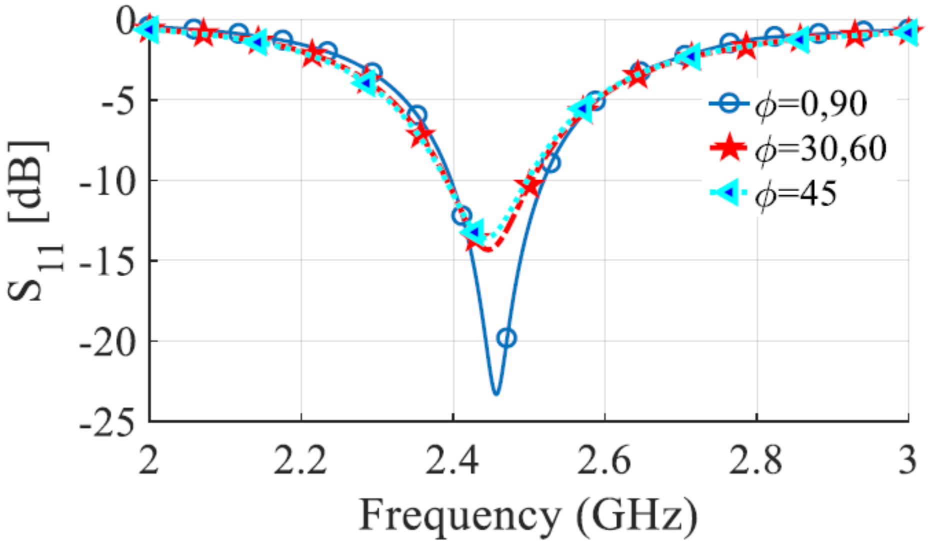


ϕ= $60^{\square}$



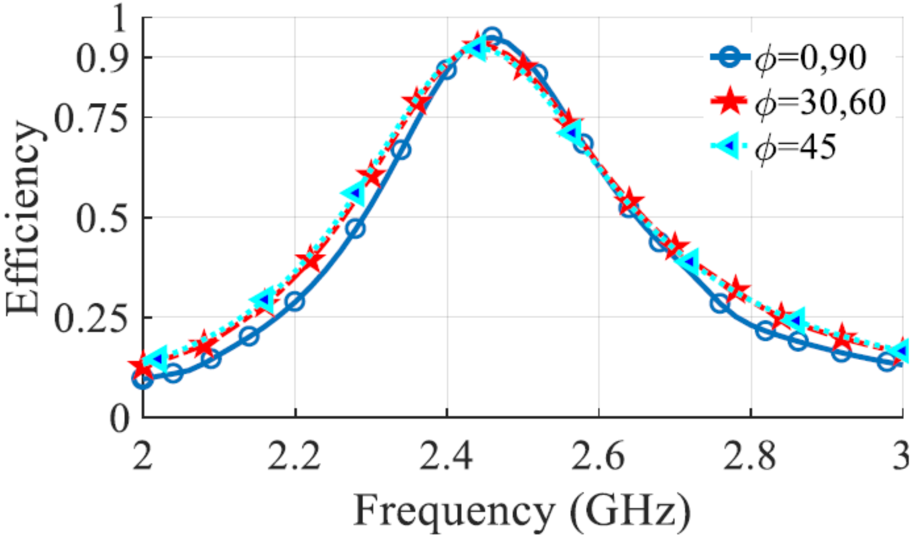
ϕ= $45^{\square}$

Unit Cell Performance



Absorption Performance

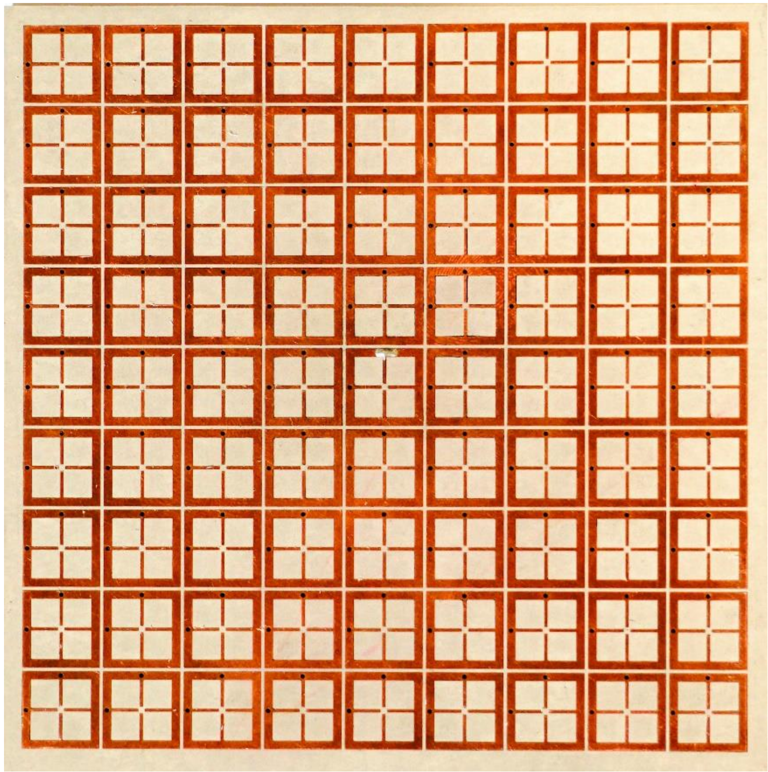
Harvesting Performance



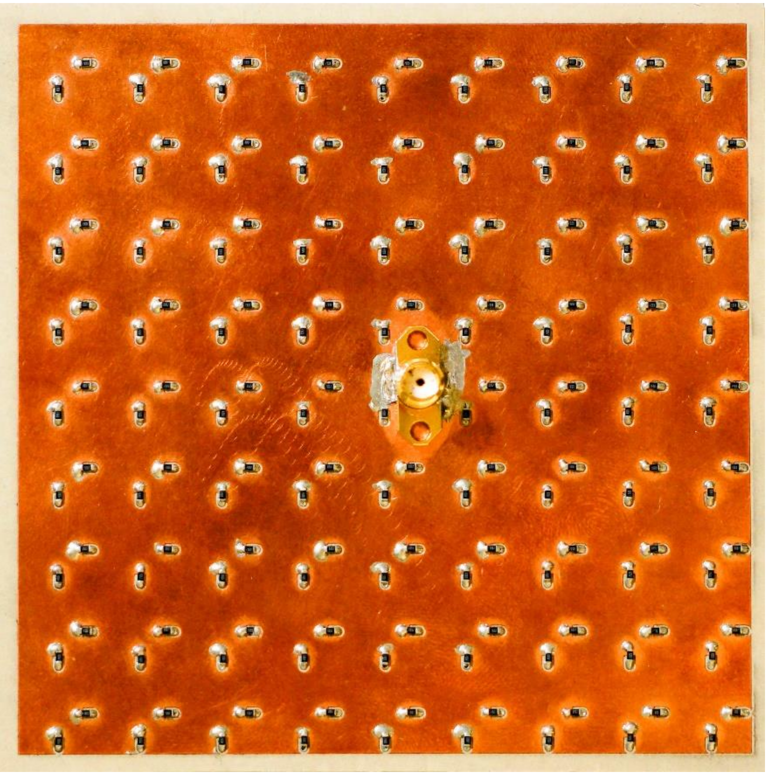
$$\eta = \frac{P_{loads}}{P_{inc}}$$

$$P_{inc} = (Power\ Density) * (Unit\ Cell\ Area)$$

Fabricated Array

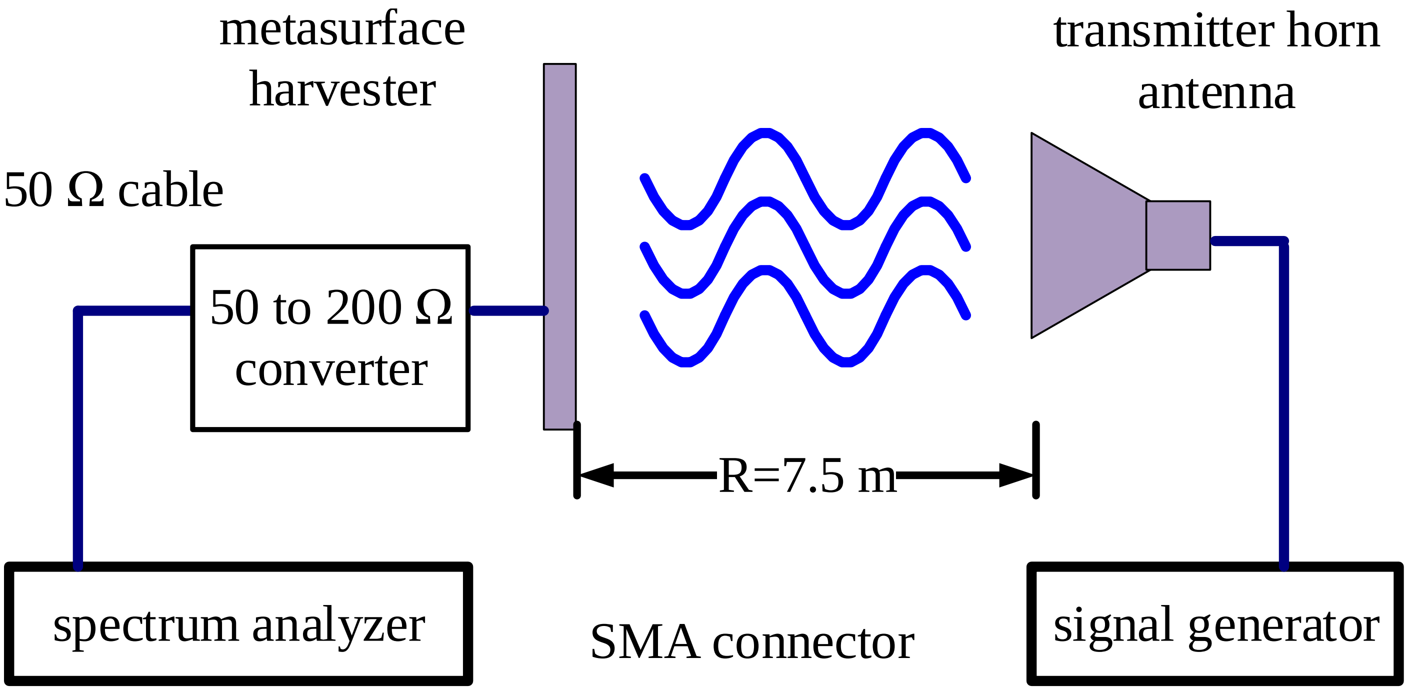


Top View



Bottom View

Measurement Setup



metasurface harvester

transmitter horn antenna

50 Ω cable

50 to 200 Ω converter

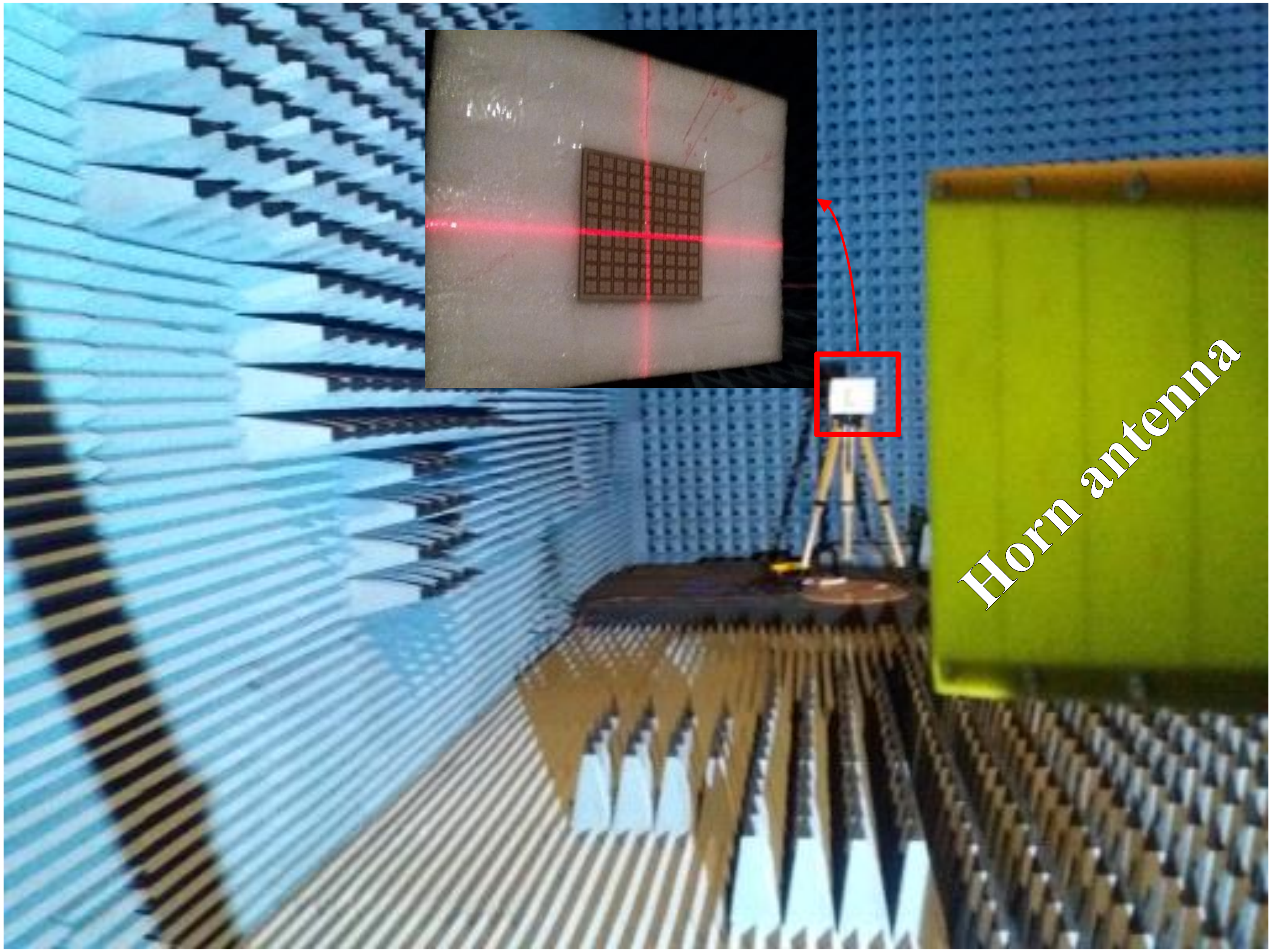
R=7.5 m

spectrum analyzer

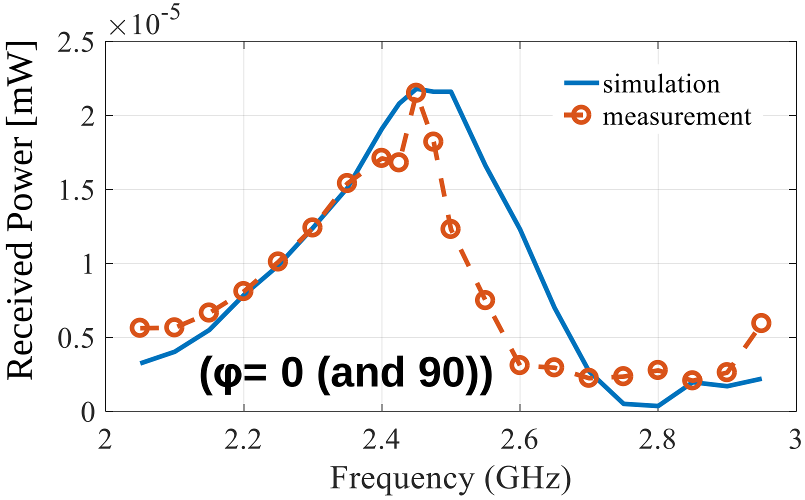
SMA connector

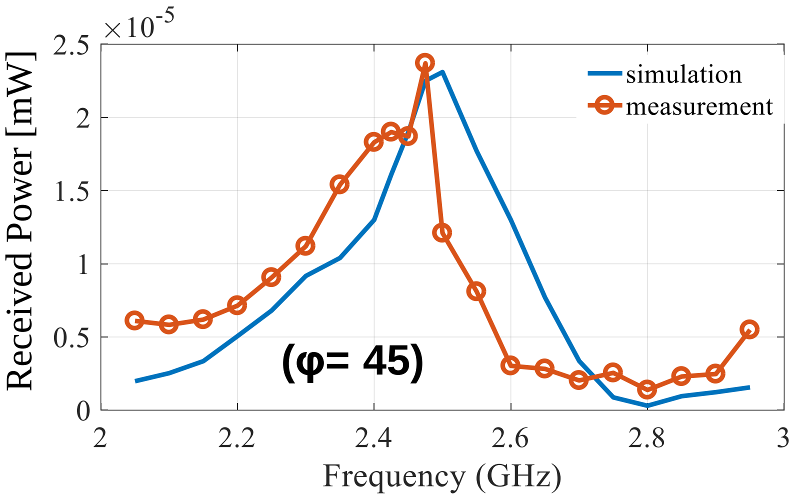
signal generator

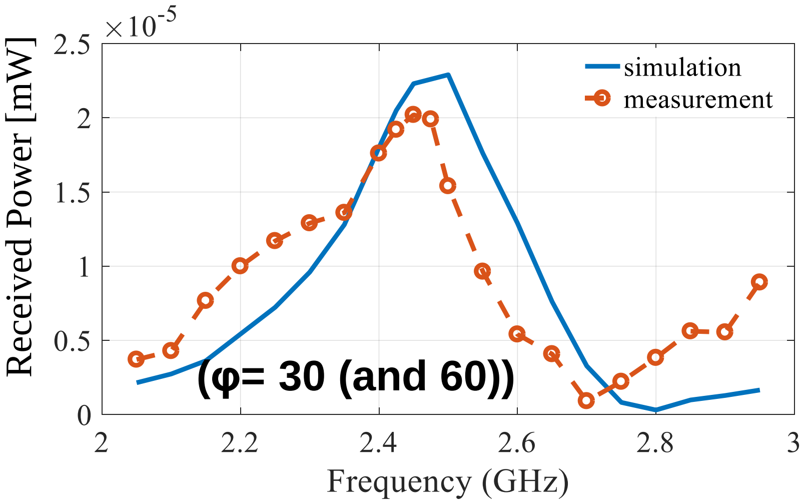
Measurement Setup


Horn antenna

Results



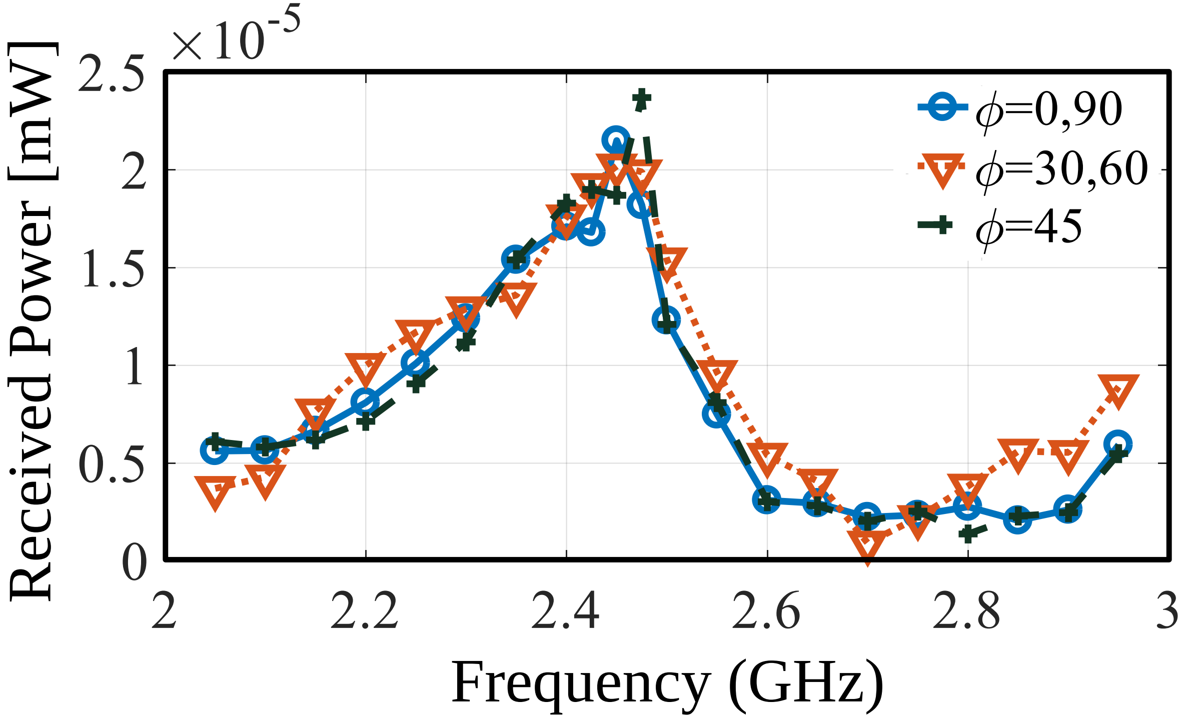




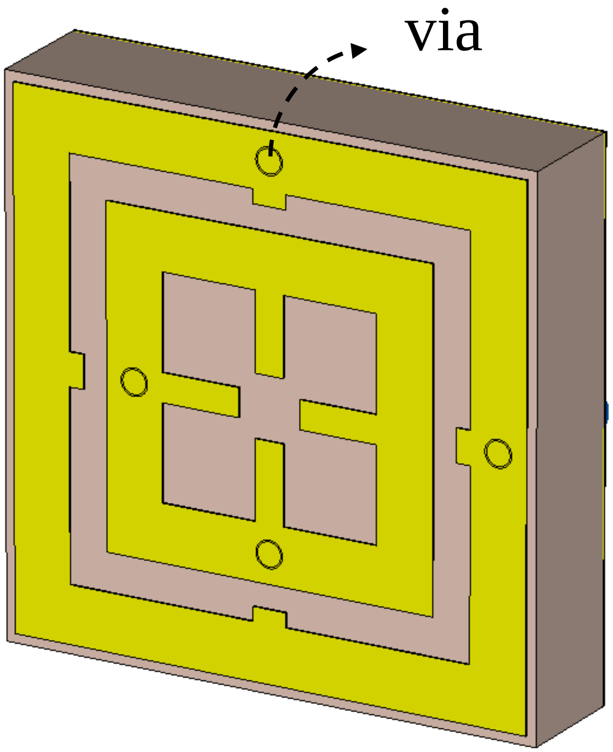
The simulated and measured output power of the central cell for different polarization angles of the incident field.

Results

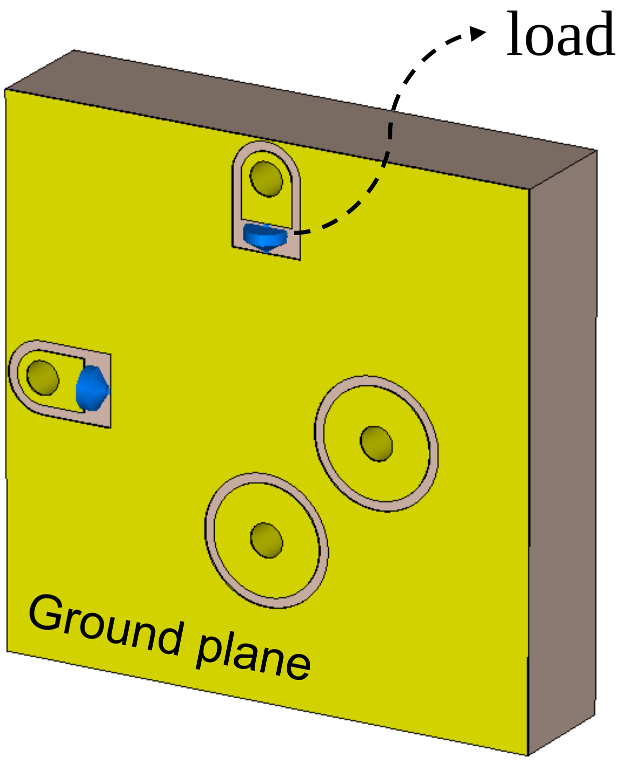
The measured power for different polarization angles



Resonator for Dual Pol. & Dual Band



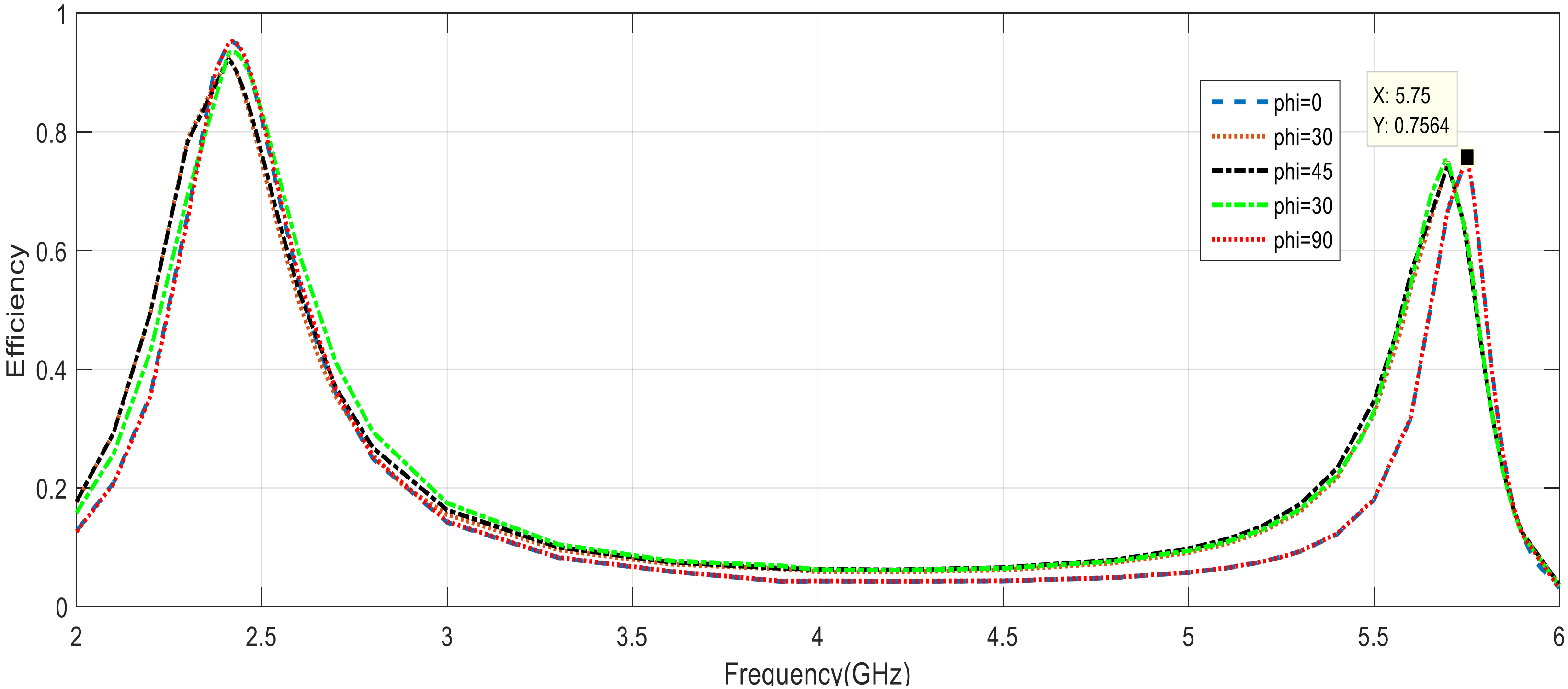
Top View


load
Ground plane

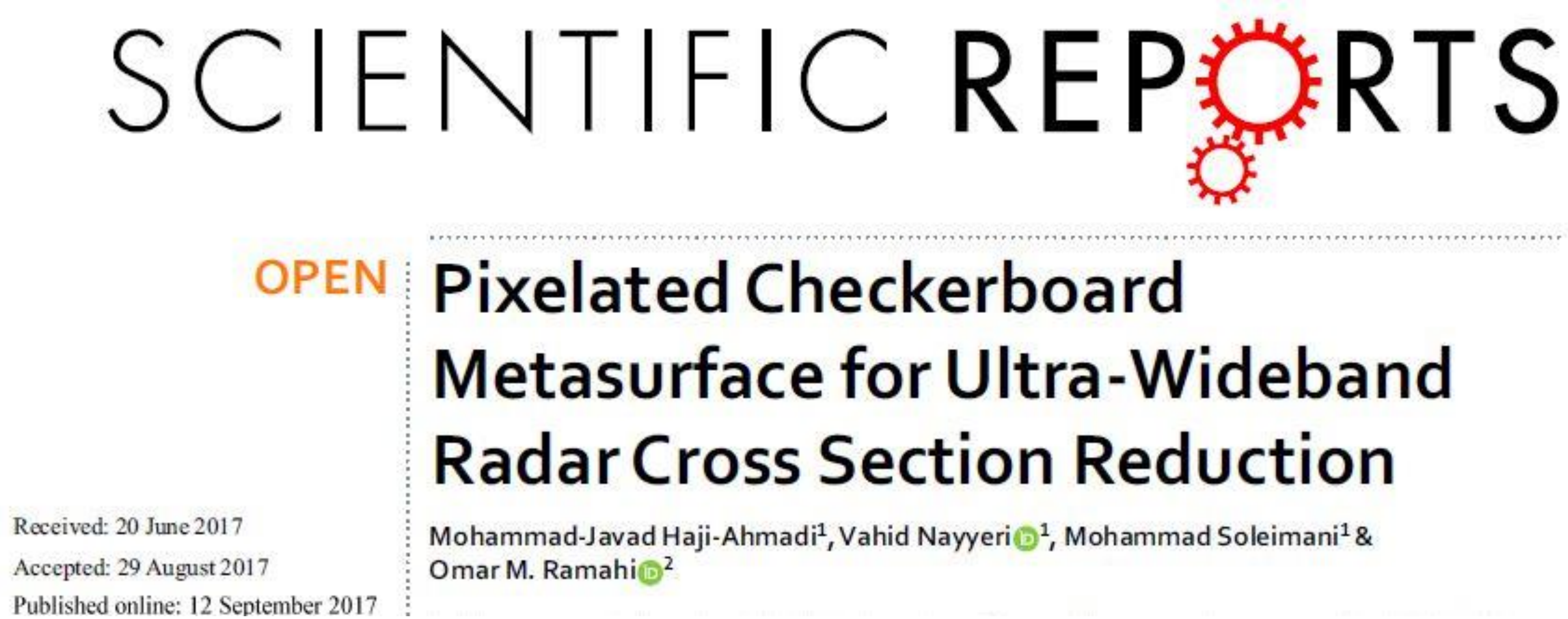
Bottom View

Resonator for Dual Pol. & Dual Band

Not good efficiency in both bands ☹



Pixelated Cell



SCIENTIFIC REPORTS

OPEN

Pixelated Checkerboard Metasurface for Ultra-Wideband Radar Cross Section Reduction

Mohammad-Javad Haji-Ahmadi[1], Vahid Nayyeri[1], Mohammad Soleimani[1] & Omar M. Ramahi[2]

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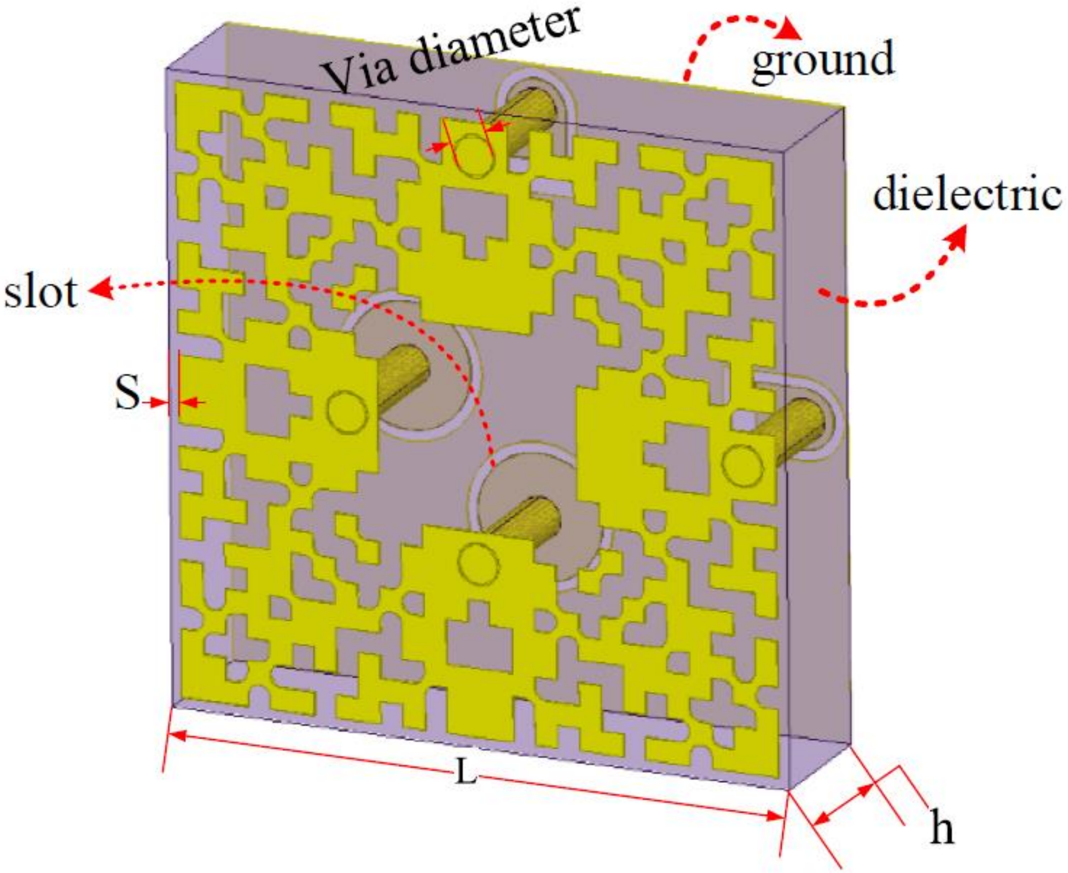
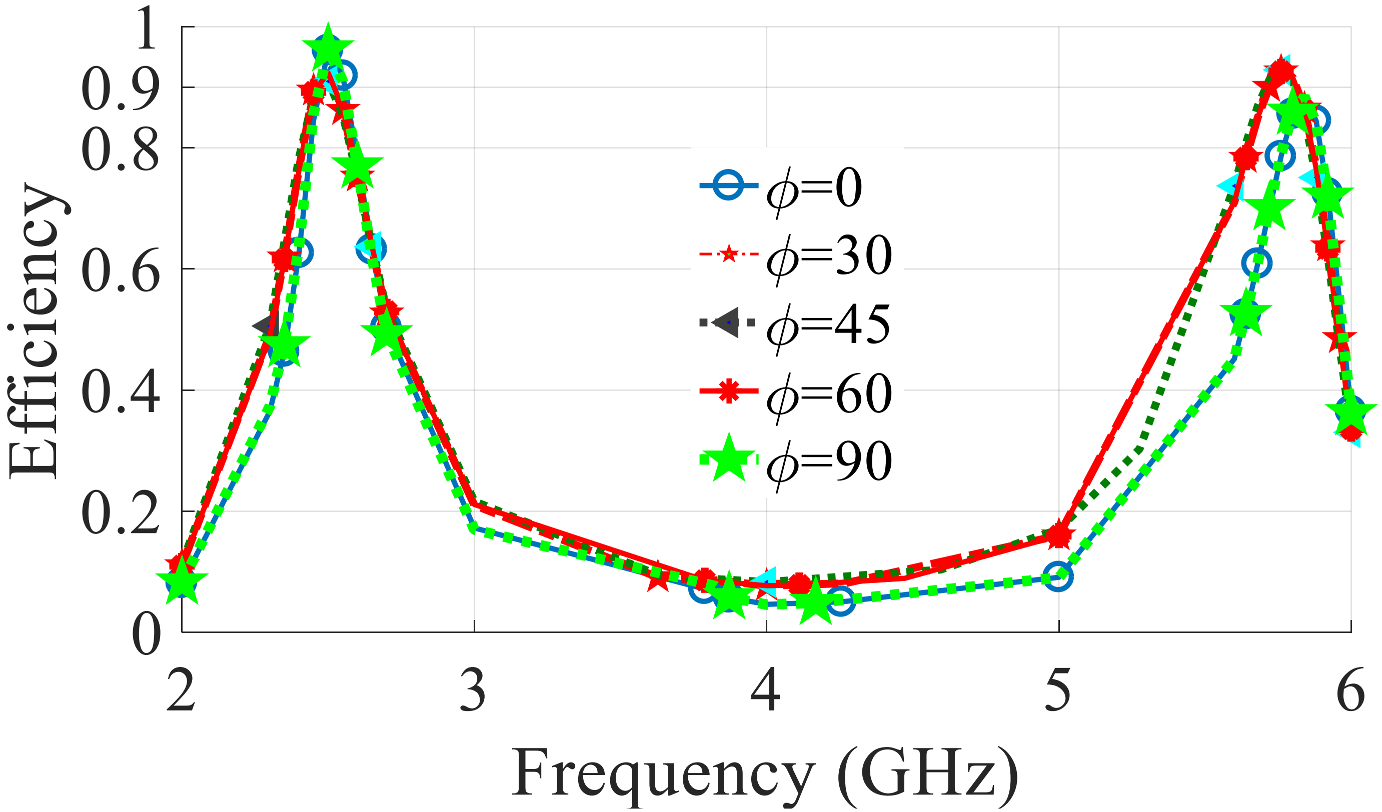
Pixelated Cell

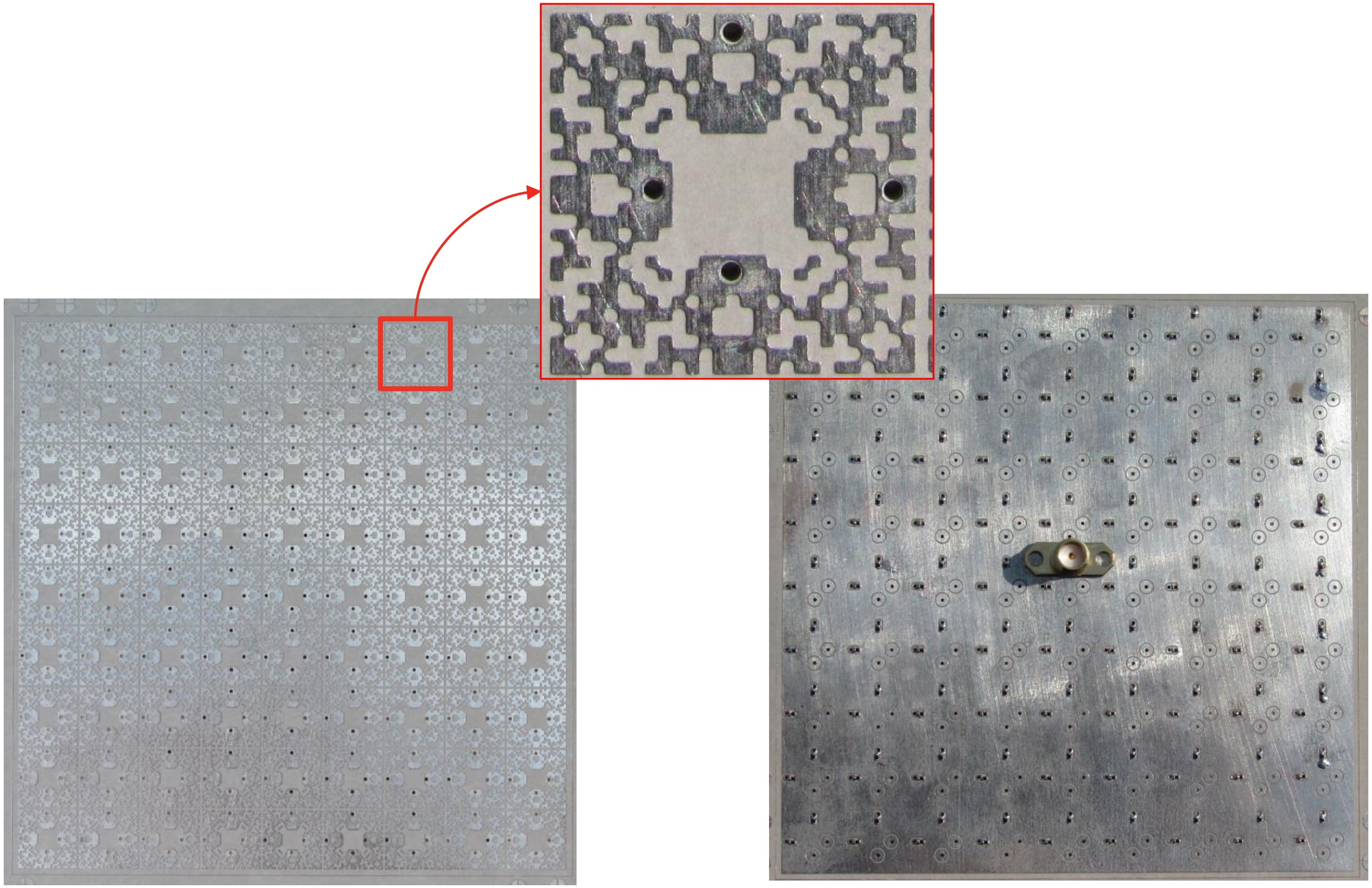

Via diameter
ground
dielectric
slot
S
L
h

Results

Great efficiency in both bands ☺



Fabricated Array



Thanks for Your Attention!
Any Question?

References

Alavikia, B., Almoneef, T.S. and Ramahi, O.M., 2015. Complementary split ring resonator arrays for electromagnetic energy harvesting. Applied Physics Letters, 107(3), p.033902.

Xu, P., Wang, S.Y. and Geyi, W., 2016. Design of an effective energy receiving adapter for microwave wireless power transmission application. AIP Advances, 6(10), p.105010.

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B. Ghaderi, V. Nayyeri, M. Soleimani, and O. M. Ramahi, "Multi-polarisation electromagnetic energy harvesting with high efficiency," IET Microwave Antennas Propagation, vol. 12, no. 15, pp. 2271-2275, 2018.

B Ghaderi, V. Nayyeri, M. Soleimani, and O. M. Ramahi, "Pixelated metasurface for dual-band and multi-polarization electromagnetic energy harvesting," Scientific Reports, vol. 8, p. 13227, 2018.